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Implementation solutions for greenhouse gas mitigation measures in livestock agriculture: A framework for coherent strategy

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Abstract

Globally, progress in reducing greenhouse gas (GHG) emissions from livestock agricultural systems has been slow. Attention has focussed on implementation science: understanding barriers to the uptake of GHG emissions mitigation measures and identifying solutions. Here, solutions presented by stakeholders associated with the Welsh sheep, beef and dairy sectors were used to create a typology of implementation strategies providing insights for improving uptake of GHG emissions mitigation measures in these sectors globally. A grounded theory approach identified themes and underlying categories of solutions in data gathered from stakeholders, through semi-structured interviews and facilitated workshops. Four categories were identified, underlying 25 themes coded from the data: Basis for change (relating to the knowledge, skills and resources of those involved), Levels of change (working around, overcoming or altering challenges), Approaches to change (accommodating, controlling or empowering) and Types of change (specific practical solutions or capacity-building). Basis for change and Approaches to change determine responsibility for change

from practical (who has the capacity) and subjective (who should be responsible) perspectives. The typology is discussed in the context of previously identified challenges and examples of current implementation strategies. Findings provide a framework of solutions to support policymakers, and researchers engaged in implementation science.

Key words: climate change, greenhouse gas mitigation, implementation science, livestock agriculture, stakeholders

Introduction

The urgency of reducing greenhouse gas (GHG) emissions to avoid severe climate change impacts is becoming increasingly clear (IPCC, 2018). The livestock agricultural sector is estimated to contribute around 13% of global anthropological GHG emissions (Ripple et al., 2013) making mitigation a major priority (Beddington et al., 2012). Many mitigation strategies for agriculture have been explored, often representing efficiency gains for farmers as well as reducing emissions (Beukes et al., 2010; Valin et al., 2013). However, many barriers exist to the uptake of climate-friendly farming techniques (Smith et al., 2007; Wreford et al., 2017). Although specific barriers vary with environmental, economic and farming system contexts (Feliciano et al., 2014), recent work suggests that categorisations of challenges developed from local studies have relevance at the global level (Kipling et al., 2019). An increasing body of work has focussed on identifying such challenges by gathering information from stakeholders (Burbi et al., 2016) and exploring their preferences in terms of the changes to be implemented (Jones et al., 2013). Other studies have focussed on costs, benefits and uncertainty in the effects of changes, supporting the prioritisation of the most economically effective mitigation measures (Eory et al., 2018; Jones et al., 2015). However, growing understanding of farmers' motivations suggests that their interests and perspectives go far beyond profit

maximisation, with advances in psychology and behavioural change demonstrating the impact of many different influences on decision-making (Darnton and Evans, 2013; Inman et al., 2018; Morris et al., 2017; Wynne-Jones, 2013).

Much work has been undertaken to develop solutions to barriers to the implementation of mitigation measures, as recently summarised by the Organisation for Economic Cooperation and Development (Wreford et al., 2017). International commitments to reduce emissions have driven policymakers at national level to address climate change, with the emergence of strategic initiatives to spur on-the-ground change, such as the Scottish Government's Farming For a Better Climate (FFBC) scheme (SRUC et al., 2018). Despite this, few studies have attempted to create a framework coupling the underlying characteristics of challenges and available solutions. The Welsh Government has prioritised reductions in GHG emissions (WG, 2016) and committed itself to long-term sustainability (WG, 2015), funding the Climate Smart Agriculture Wales (CSA Wales) project to support it in identifying effective and sustainable solutions for reducing emissions from livestock agriculture. Within CSA Wales, the current study collected and analysed the views of stakeholders in the Welsh livestock agricultural sector on how to improve the uptake of GHG mitigation measures, developing a typology of solutions associated with previously identified challenges to change (Kipling et al., 2019). The typology was used to categorise implementation tools described in a recent global review (Wreford et al., 2017), demonstrating its application to identify gaps, opportunities and potential problems with strategies aimed at driving GHG mitigation in the livestock agriculture sector.

Methods

Data were collected through 18 semi-structured interviews with stakeholders, and two stakeholder workshops. The approach was described by Kipling et al. (2019) including details of the number and types of stakeholders participating (Appendix A). Identification of the challenges described in this earlier paper preceded discussion of potential solutions, which are reported here.

The research team undertook a mapping process to identify relevant stakeholder groups that affect or would be affected by the implementation of GHG mitigation measures on livestock farms in Wales (Freeman, 1984). The process involved the Agriculture Industry Climate Change Forum (AICCF) – a key Welsh research-policy-stakeholder group formed to address issues associated with agriculture and climate change. The AICCF formed the initial sample of interview and workshop participants, with snowball sampling identifying further individuals and organisations for involvement (Feliciano et al., 2014). Farmers, farming unions, countryside and agricultural interest groups, industry bodies, farming consultants, policymakers and conservation organisations were engaged as participants. The semi-structured interviews lasted around one hour and utilised general, pre-prepared questions to stimulate discussions (Patton, 1990); the number and length of interviews was consistent with other recent farming systems studies (Morris et al., 2017).

In addition to the interviews, two workshops were held at Aberystwyth University during October 2017 and involved 22 stakeholders from 13 organisations, including mapped stakeholder groups (see above) as well as individual farmers. The workshops focussed on dairy and on beef and sheep production systems, and were organised using a structure based on the ‘Future Workshop’ method (Jungk and Müllert, 1987) which involves participants discussing ideal scenarios, perceived challenges to reaching ideal situations, and what solutions might tackle those challenges. Work was undertaken in small, facilitated groups. Mitigation measures were defined as actions which could

95 reduce emissions or increase carbon sequestration without causing carbon leakage through reduced
96 production (Fellmann et al., 2018; Huang et al., 2011). The implementation of mitigation measures
97 was treated as the ideal scenario to be aimed for (in this way, problems relating to scientific
98 knowledge and efficacy were open for inclusion by participants as barriers to change). Following the
99 identification and discussion of challenges to change, described fully by Kipling et al. (2019) and
100 involving the workshop groups considering challenges relating to specific parts of the farming
101 system, participants were invited to put forward and discuss possible solutions, with each idea
102 recorded on sticky notes to avoid biasing inputs towards speakers with more confidence (Kitzinger,
103 1995).

104
105 Transcribed data from interviews and workshops was analysed using a grounded theory approach
106 (Charmaz, 2014; Glaser and Strauss, 1967) in which data were coded into themes and compared and
107 contrasted to identify underlying categories providing insight into the research question – here, to
108 understand the kinds of solutions available to tackle the identified challenges to implementing GHG
109 mitigation measures on Welsh livestock farms. Grounded theory approaches avoid forcing datasets
110 into predetermined categories with which they may not align, instead using close analysis of the
111 data themselves to allow categories grounded within the dataset to emerge (Charmaz, 2014; Glaser
112 and Strauss, 1967). As issues related to implementing GHG mitigation measures have previously
113 been found to be sensitive to the context of change (Feliciano et al., 2014), this approach was
114 considered of particular relevance in the current study. Across the interviews and workshops the
115 dataset reached saturation, with no new themes or issues arising as successive data were analysed
116 (Charmaz, 2014). Categories identified in the dataset were organised into a conceptual framework
117 and used to analyse current approaches to implementing GHG mitigation measures in agricultural
118 systems, to highlight new insights arising from this study. Specifically, the conceptual framework was
119 applied to implementation tools reviewed at global level for the OECD by Wreford et al. (2017) to

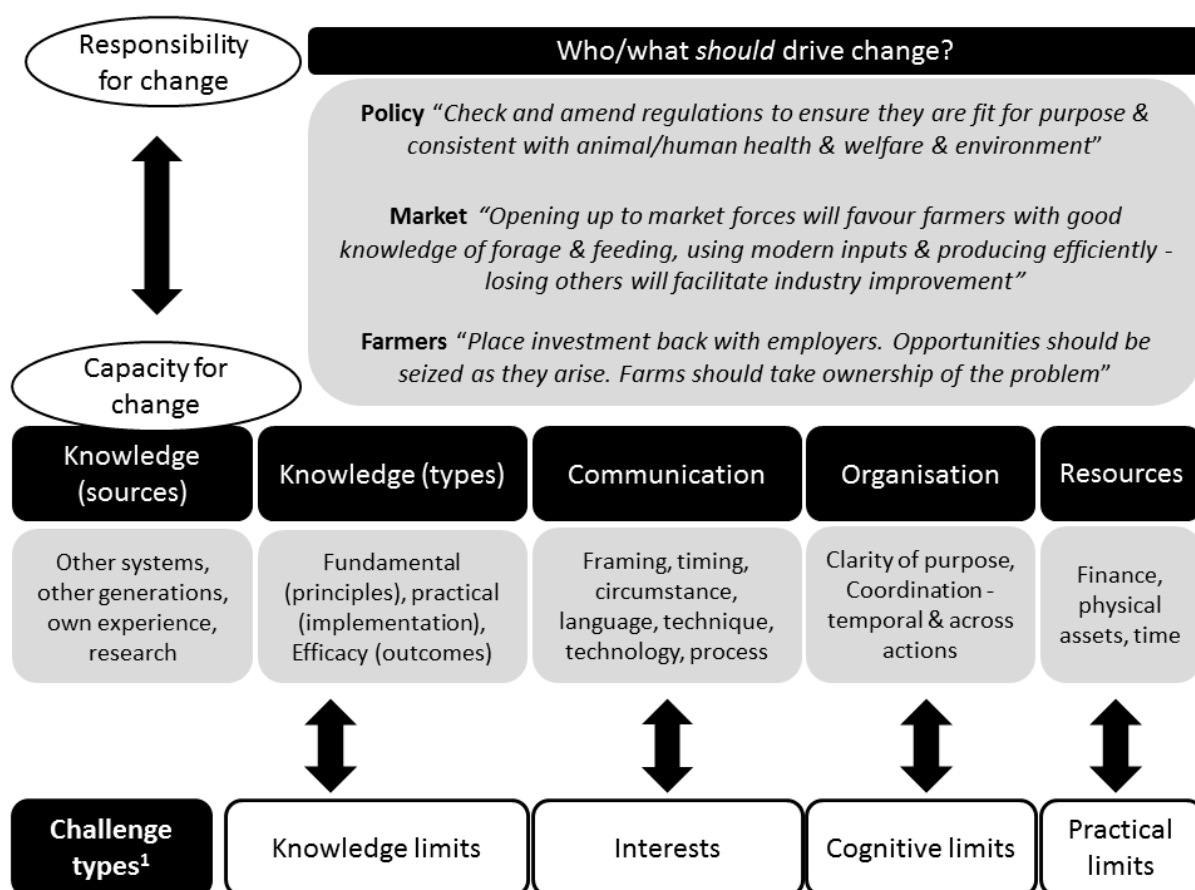
demonstrate its use in gaining understanding of the scope, limitations and potential consequences of different implementation strategies.

3. Results and Discussion

Twenty five themes relating to solutions were identified within the workshop and interview data (full description of themes in Appendix B) and grouped into four underlying categories: Basis for Change, Type of Change, Level of Change, and Approach to Change.

3.1. Basis for change

This category arose from comments relating to the structures, aims and philosophies underlying change (Fig. 1). It was made up of two elements: Responsibility for change, and Capacity for change. Responsibility for change incorporated views expressing or implying preferences or assumptions about whether market forces, the government or other stakeholders should drive change. Responsibility can also be shared between government and other stakeholders within the broader framework of the market.



¹Categories of challenge affecting stakeholder groups identified by Kipling et al. (2019)

Fig. 1: Basis for change: The decision about which group(s) or institutions should drive change is both normative and practical. The practical aspect is associated with the elements of Capacity for change, and how these are distributed across stakeholder groups.

Capacity for change incorporates five elements (Fig. 1); how capacity is distributed between different institutions forms the practical aspect of Responsibility for change. Participants' comments suggested three types of knowledge were relevant to implementing mitigation measures: 1) fundamental knowledge about the system and potential improvements to it "Research needs to identify alternatives to straw for use in loose housing systems" 2) practical knowledge of how fundamental knowledge can be translated into use "Improved delivery mechanisms for supplements to animal – need practical products" and 3) knowledge about efficacy, derived from on-farm data

148 collection measuring the effects of farming practice: *“Need to have information to understand which*
149 *parts of the farm are efficiently managed, and which not, to focus improvements”*

150

151 Types of knowledge were associated with sources of knowledge, including knowledge generated in
152 other systems *“Learning from other systems and countries can be valuable”*, knowledge gained
153 through previous experience *“Improving engagement through previous experience, use of things like*
154 *systems where you opt out (not in) e.g., with BVD”* and inter-generational knowledge transfer *“Help*
155 *students to develop skills in agriculture; farmer-student partnership”*. Research was considered an
156 important source, particularly of fundamental knowledge.

157

158 Communication related to the capacity of the system and those within it to share information, ideas
159 and understanding effectively *“We need to think about how to guide people with good advice,*
160 *reasoning and understanding of why things are happening”* based on recognition of communication
161 as a skill having several facets (Fig. 2) and requiring training and constant improvement *“Bring in CPD*
162 *for farm advisors, to ensure information and techniques for engagement, are kept up to date”*.

Framing	"Sell climate change at the same time as efficiency to farmers - use win wins"
Timing	"Timely dissemination of knowledge in line with support"
Circumstance	"Talking to farmers in groups and giving advice may be better than one-to-one consultation, because the farmers can discuss and work through those aspects of social risk"
Language	"De-mystify breeding topic & jargon to empower farmers to ask the right questions & make the right choices for them"
Technique	"Diverse KE to fit different learning types of farmers – practical & visual (seeing change in action) often works well – but not for everyone – mix important"
Technology	"To get understanding of issues need farmer friendly tools like FarmBench"
Process	"Communication & approaches that can lift farmer self-esteem & positivity – more likely to engage & change approaches"

Fig. 2: Facets of communication (black boxes) and example quotes from participants (white boxes)

The third aspect of the category, Organisation, concerned the institutions facilitating change in the livestock agricultural sector. This aspect arose from themes including 'Joined-up policy' emphasizing how policy was considered the main driver of change in the current system. Organisation incorporated three elements: 1) clarity *"Collaboration with government required to clarify goals and how they can be achieved"* 2) coordination of policy over time *"Policy support and grants in place to match timeframe of changes"* and across different decision-making domains *"Coordinated, joined up thinking at policy level to avoid contradictions – Wales is small enough to make this work"* and 3) the need for increased predictability *"Need policy certainty – will policy be decided at UK or Welsh level etc. Progress must take place in this context"*

Finally, the need for adequate resources was emphasized *“Profitability of farms, tax regime and allowances (e.g., currently there are good incentives on machinery but not buildings) – if these are not favourable, additional information/advice doesn’t tend to improve uptake”*.

3.2. Type of change

Participants’ comments represented two solution types: 1) practical actions to reduce emissions, and 2) actions to build capacity for change. The first were technical and specific, e.g., *“Fertilisation for production is best with manure or legumes”* emphasizing solutions with multiple benefits *“For beef systems, sexed semen is important – win win efficiency and emissions”*. The second type focussed on implementation, such as *“Sharing of machinery has been set up, with training in some areas”* or identified broader principles for improving capacity for change *“Cooperation between farmers required to attain critical mass in supply etc. of products from new systems”*. There was an emphasis on working together *“Collaboration with government required to clarify goals and how they can be achieved”* and specialisation (implying inter-reliance) *“Farmers may not be best placed to undertake environmental work – specialist contractors etc. may have an important role – needs collaborative exploration with government”*. Some comments considered more radical changes to land management, based on such principles *“Claris project – learning lessons from estate management, where there are managers for each part of the system under the landowner. Expert can rent land (e.g., to grow potatoes) with a system to ensure long-term commitment to quality (e.g., might get same field each time they rent, to avoid incentive to seek short-term gain at long-term cost)”*

3.3. Level of change

199 Three levels of solution were identified in participants' comments (Fig. 3). Although the focus was on
200 farmers, the levels were also relevant to implementing change in the activities of customers,
201 suppliers, researchers, policymakers etc. For example: "*Flat fee for vets so they are then incentivised*
202 *not to prescribe antibiotics*", a Level 3 solution aimed at altering the barrier to change (removing
203 incentives for vets to sell antibiotics). The examples (Fig. 3) also demonstrate how measures can act
204 on different types of barrier. For example, tax breaks for improving long-term sustainability
205 overcome both, barriers related to motivation (challenge category of Interests) but also help
206 overcome practical (cost) barriers to changes actually desired by a farmer. The relationship between
207 overcoming and altering solutions may be negative – e.g., providing funds to buy a particular
208 product (Level 2) does not alter the barrier of costs, and in fact suppliers may benefit by increasing
209 their prices in response, raising the barrier. This property of solutions makes unintended
210 consequences possible, such as punishing a behaviour thought to be driven by farmers' Interests,
211 when barriers to change were in fact practical. This underlines the importance of correct diagnosis of
212 challenges faced before action is taken (Kipling et al., 2019).

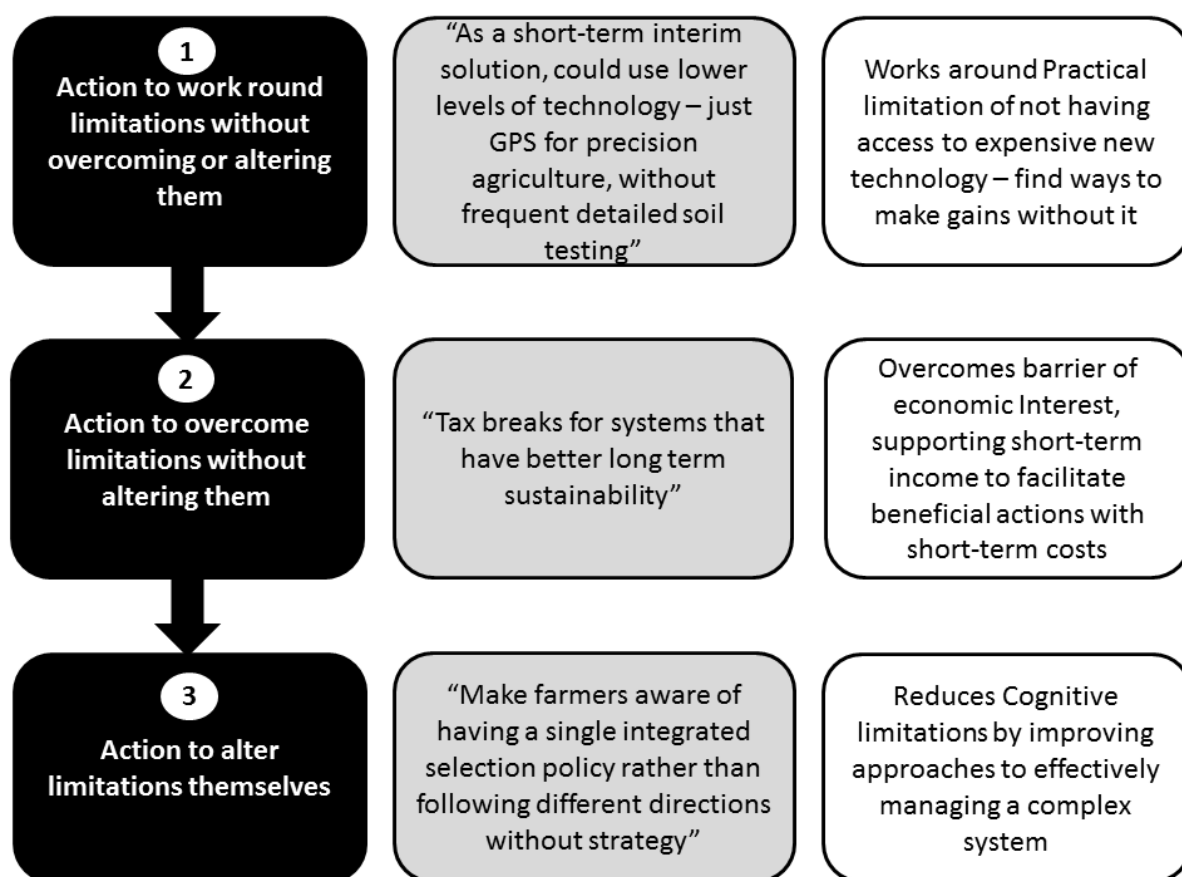


Fig. 3: Levels of change (black boxes) with example quotes from participants (grey boxes) and explanations of the examples (white boxes)

3.4. Approach to change

Three approaches to change were revealed in workshop and interview data: Accommodate, Control and Empower.

An Accommodating approach describes actions which accept challenges and take them into account when setting targets. This approach emerged from several comments, including: *"Simple approaches (e.g., matchbox height to measure sward) can provide easy wins in terms of improved management"*.

The approach is associated with the 'working around' level of change. However, working around

solutions can include strong interventions elsewhere in the system that make the focus challenge less important: e.g., the use of specialist contractors can work around a lack of skills or motivation in the farming community without altering it *“Use of contractors with expertise in hedgerow/tree management to manage and improve habitats and take off material (e.g., for bio-refining)”*. In contrast, an accommodating approach uses minimal intervention, relying on others (stakeholders and/or the market) to drive change. Solutions offered take into account existing limitations *“The key will be having practical and simple options. Have to be realistic about the challenge – should aim for small number of changes at first and build gradually”*.

The second approach to change identified was Control. Regulations, payments and incentives are included as controlling approaches, e.g., *“Perhaps expand NVZ across all Welsh farms in future – this would be contingent on sufficient availability of grant money for implementation”*. Classing incentives and payments as controlling rather than empowering may seem counter-intuitive, but focusses on how the institution (e.g., government) making the payments decides which groups and individuals can access them, and for what uses. The more scope recipients have to choose how payments are spent, the more control shifts towards empowerment, creating a continuum between the two. Providing incentives designed to overcome Interests viewed as damaging, is clearly controlling. However, payments aligned with farmers interests, helping them overcome Practical barriers, are empowering.

A key element of control, was the development of more specifically prescribed solutions *“Tailored measures are important: 80% of Wales is Less Favoured Area, but systems vary – effective identification of land types and tailoring of measures is therefore important”* which rely on detailed performance data *“Productive Lifetime Index (fertility, health and production) can be increased, and*

249 *those that take up this option include in their herd report, so that it is easy to measure uptake*” as
250 well as data about stakeholders themselves *“Align KE and policy to knowledge about different types*
251 *of farmer (research into segmentation of farmers by type)”*. The top-down nature of these solutions
252 is highlighted by the use of external experts to direct change *“Need system that is not reliant on tick*
253 *boxes, but utilises experts to get tailored approach”*.

254

255 Data collection enabling locally relevant strategies to be developed is also an important element of
256 an empowering approach (see below); the difference is that under a controlling approach, the focus
257 is on collecting information *about* farms and practices to enable more effective policy with fewer
258 unintended consequences. Farmers become implementers of decisions made elsewhere, providing
259 services that society expresses the need for via government. Responsibility lies with government (or
260 with industry bodies working with government), with change driven top-down: *“A driver of change is*
261 *likely to be aggressive best practice policy targets in future, targeted at microbial resistance – this*
262 *will restrict products used”*

263

264 Control can be exerted on the actions of groups other than farmers, changing conditions for farming
265 and enabling the adoption of mitigation measures and more sustainable practices. In this case, from
266 the perspective of farmers the outcome may be empowering. Examples include changes focussed on
267 customers *“Need to maintain milk prices/have set price contracts which are for the long-term, to*
268 *enable farmers to realise the benefits of the changes they have made”* and on suppliers *“More*
269 *proactive approach by vets – more visits and advice/consultancy role”*

270

271 The third Approach to emerge from the data was Empowerment, based in comments about the
272 quality of information farmers can access, their knowledge of practical and managerial skills and the

opportunities and systems facilitating knowledge-sharing. Some resources to enable learning were emphasized *“Give farmers a sense of ownership – use of motivational interviewing and Action Learning to facilitate long-term change”* as well as the need to treat farming as a profession *“Investment in CPD (e.g., in Ireland farmers undertaking CPD tend to apply for more grants for farm improvement)”* and for farmers to be given a wider perspective on the industry *“Climate change needs to become main-stream in agricultural college curriculum – all degrees should be framed in terms of holistic sustainability”*. Participants also focussed on opportunities for knowledge-sharing *“Positive option is to facilitate sharing the positive experiences of farmers who have undertaken agroforestry, to spread skills and build confidence”* including between generations *“Need for skilled & knowledgeable labour – career farmers: requires continuity and sharing between generations”* and along the supply chain, whether from supplier to customer *“Need more subtle information on herd health, e.g., scoring system or (best) database of herd information so that buyers can understand a herd's health status and the risk of buying much better, than the over-simple TB high risk area information. This info also drives farmers to take responsibility for herd health and husbandry”* or from customer to supplier *“Need follow through information to demonstrate the performance of progeny – e.g., a database – and farmers need access to this”*.

Participants highlighted that sharing information can only be empowering if it is independent and of high quality; enabling informed decision-making rather than selling a particular approach or strategy (representing an attempt to control) *“Provide independent information from non-salesmen that empowers farmer when making choices”*. The provision of more strategic knowledge was suggested, to support farmers in managing change themselves, rather than implementing actions as instructed by others *“Vets can go a step further – from just dealing with the initial problem to offering advice on better practice – they are trusted providers of information”*.

A final element of empowerment arose from comments about enabling farmers to collect and use their own data, putting them more in control of what and how they produce (in contrast to data about them being used to control their actions). This could be achieved through testing undertaken by farmers *“Maintain trace elements using testing and precision approaches”* or through the integration of monitoring devices into infrastructure *“Have meters on slurry tanks with print outs to check level, nutritive value etc.”*

3.5. Framework for change

The solution categories revealed by analysis of workshop and interview data, are inter-related and can be applied to tackle the challenge categories identified by Kipling et al. (2019) (Fig. 4). Levels and approaches to change are not completely aligned. Overcoming (rather than Altering) Interests can always be considered controlling, but overcoming practical limitations may empower farmers to undertake practices they wanted, but were not able to, undertake. Overcoming knowledge limitations may be achieved by providing highly specific information about practice that can be viewed as a type of control, but as following instructions still widens knowledge even such prescriptive information may empower. Controlling the actions of one group may also empower the actions of others (e.g., taxes, payments or regulation on the actions of suppliers or customers).

If Interests can be altered by providing arenas in which farmers engage with and learn about the needs, problems and motivations of other groups in society (e.g., other rural industries, conservation groups, societal representatives), controlling approaches are likely to become less necessary. Emphasis moves from overcoming Interests, to facilitating desired change, or overcoming or altering other limitations. Action to reduce Cognitive limitations, in providing targeted groups with a better strategic view of their business, its context and most-effective management, may likewise have

wider positive effects, altering Interests and supporting the identification of economic opportunities and efforts to tackle Practical and Knowledge limitations.

Accommodate (market / farmers), Control (policy / market) or Empower (shared)			
Challenge	Work around	Overcome	Alter
Practical limitations	Cheap, low effort solutions; Solutions carried out by others	Provide resources to implement actions; regulate or prohibit	Reduce resource costs through new practical solutions
Knowledge limitations	Solutions not needing new knowledge; Solutions carried out by others	Provide precise protocols to be followed	Provide practical knowledge and skills, chances to share understanding
Cognitive limitations	Solutions not needing new understanding; Solutions carried out by others	Provide decision support systems; Solutions that simplify practice	Provide management knowledge and skills, chances to share understanding
Interests	Solutions aligned to interests; Solutions carried out by others	Regulate, prohibit, incentivise or persuade	Facilitate sharing of ideas and needs between groups

Fig. 4: Types of solution associated with Levels of change (columns), Approaches to change (top box) and Focus of responsibility (text in brackets) for each of the challenge categories (rows) identified by Kipling et al. (2019).

The interaction of solution categories can be visualised as a process (Fig. 5). Who or what drives change can be a mixture of an ideological choice and practical necessity, related to the capacity of the system and the groups within it. Capacity-building solutions create systems within which specific practical solutions can be implemented. How challenges are tackled (worked around, overcome or altered) and which tools are used to achieve this (accommodating, controlling or empowering) are then choices with an impact on the targets of change (reducing emissions) but also on the capacity of the system and the groups within it to undertake future changes. These different aspects can be

worked through in any order, depending on the application of the framework, e.g., to assess current actions (starting by locating these actions in the Fig. 4 matrix) or (starting with the identification of goals or challenges) to explore potential implementation strategies, their implications and interactions.

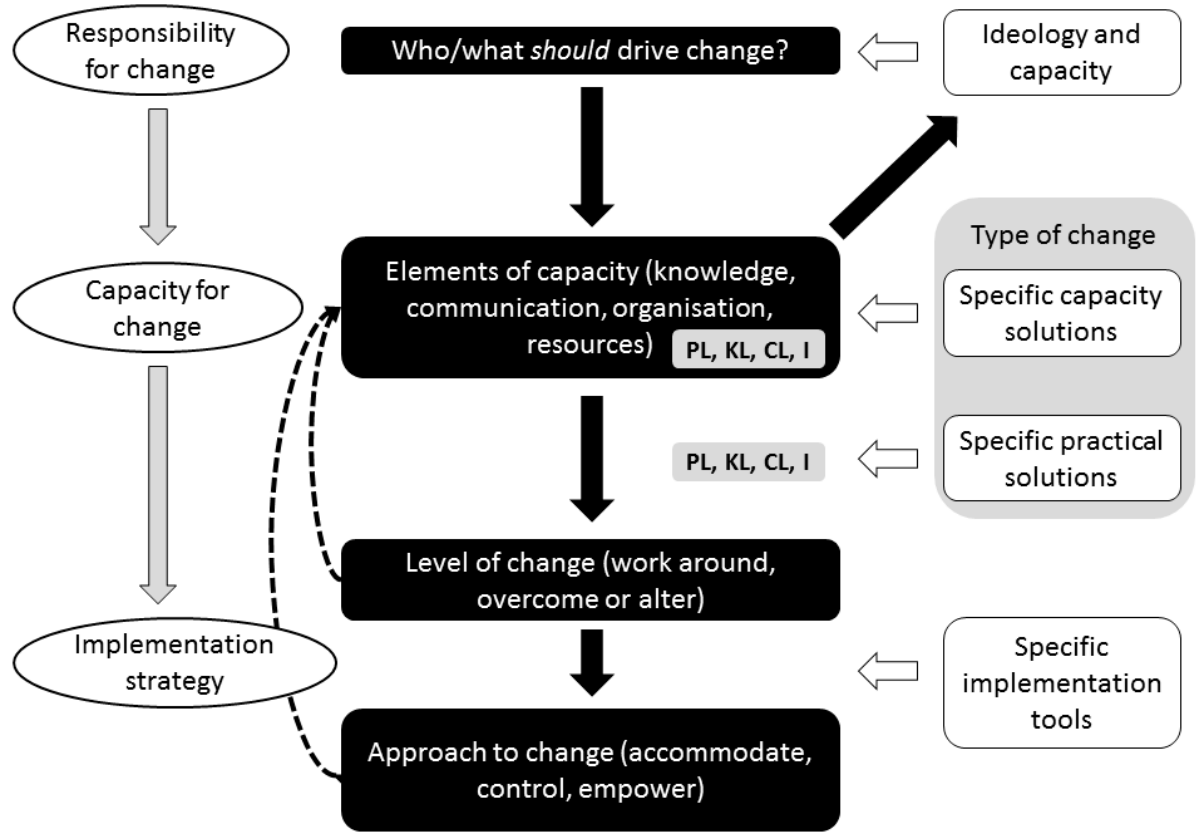


Fig. 5: Solution categories (Basis for change – Who/what should drive change and Elements of capacity, Type of change, Level of change, Approach to change) visualised in a process. Dashed arrows show implementation strategies affect future capacity for change. PL = Practical limitations, KL = Knowledge limitations, CL = Cognitive limitations, I = Interests: categories from Kipling et al. (2019).

3.6. Applying the framework to assess current interventions

The Wreford et al. (2017) global review of barriers to climate-friendly agricultural practices and how they can be tackled, considers many implementation strategies. All challenge types highlighted by Welsh agriculture stakeholders were also identified in the review although, as discussed by Kipling et al. (2019), it did not consider Cognitive limitations as a major barrier globally (Wreford et al., 2017). The review recognised that public good outcomes of mitigation suggest a role for policy in implementation: solutions imply policymakers are responsible for overseeing change (Fig. 5: Who/what should drive change). The strategies proposed can be located within the framework of Approaches to, and Levels of, change defined here (Appendix C). Although all levels and approaches were covered by strategies discussed in the review, interventions around Interests focussed on control (regulation, prohibition or incentives) or accommodation (policymakers discussing implementation with stakeholders). Solutions such as targeted KE, information provision and stakeholder-policymaker discussions may also alter Interests, but this was only implicitly recognised within the aim of increasing implementation efficiency and reducing entrenched behaviours. Similarly, Cognitive limitations may be worked around, overcome or altered by some of the proposed strategies, but actions were not explicitly focussed on improving management skills or dealing with systemic complexity. Knowledge provision is highlighted but the link between this and changing Interests is not considered explicitly. Overall, applying the framework highlights ambiguity about the extent to which strategies suggested in the review will be controlling or empowering, and about how they might interact.

The Scottish FFBC initiative (SRUC et al., 2018) included within the global review as a case study, incorporates KE resources for farmers and discussion groups based around Climate Change Focus Farms. These approaches facilitate the exchange of ideas and views, presenting evidence of implementation in a 'real-world' commercial setting. This highlights the role of Elements of Capacity (Fig. 5) in utilising pre-existing Focus Farms as a Basis for change, while focussing on the importance

of stakeholder interactions. Such interactions can be powerful in altering Interests and empowerment (Inman et al., 2018), but whether these or more controlling approaches dominate depends on the nature and purpose of the processes, and the groups involved. Using the framework reveals the importance of working around (accommodating) Interests and limitations for the FFBC strategy (voluntary approach, emphasis on efficiency, business performance, simple measures and trusted information sources) while highlighting control present in the threat of regulation if these approaches are not successful.

Applying the framework presented here to the Wreford et al. (2017) review, demonstrates its value in systematically exploring interactions between and consequences of different interventions for different challenge types and stakeholder groups. The category 'Approaches to change' highlights the need for those responsible for change to be aware of how interventions may control rather than empower different stakeholders and stakeholder groups, and the implications of this. The framework also draws attention to the potential multiple benefits associated with some interventions, enabling decision-makers to optimise implementation strategies to achieve multiple aims.

3.7. Considering possible strategies for change in the context of the framework

One difference between the current study and the review of Wreford et al. (2017), is that the latter frames the Interests of farmers as given, limiting interventions to working around or overcoming this category of challenge. Implementation strategies to overcome a lack of motivation or opposition from farmers then rely on regulation, payments or penalties, constituting efforts to control behaviour and align it with pre-determined goals. Advances in modelling and data collection technology make it possible to imagine better-informed, and therefore more effective, top-down

regulatory and payment schemes, in which improved information flows support controlling strategies for change (Pacini et al., 2015). However, increasingly hierarchical systems can undermine social capital, breaking down ideas of reciprocity and trust within communities (Svendsen and Svendsen, 2000). Further, solutions reliant on payment for the provision of public goods rely on an assumption that farmers' driving interest is profit maximisation. Work on motivations of farmers in Wales has demonstrated that this is an oversimplification (Morris et al., 2017; Wynne-Jones, 2013), with human choices driven by various values and influences (Darnton and Evans, 2013; Schwartz, 2006). Strategies prioritising economic self-interest may affect the application of these values, producing unwanted behavioural changes, e.g., the financial incentives within payments for environmental services schemes may crowd out existing motivations for implementing environmentally friendly practices (Wegner, 2016). Regulatory control also puts pressure on regulators' coordination and monitoring capacity. Studies of impacts of and responses to the implementation of regulation-based Nitrogen Vulnerable Zones (Nguyen et al., 2014) demonstrate that regulation can produce unintended consequences and sub-optimal actions, while losing the goodwill of practitioners, who become antagonists rather than participants in solving problems. Wreford et al. (2017) highlight how the voluntary nature of the FFBC initiative garnered the goodwill and support of farmers for climate-friendly practices, while poorly coordinated and conflicting policy was identified as a specific challenge to implementing mitigation measures by Welsh farmers (Kipling et al., 2019).

Another solutions category arising from participants' comments was that of building capacity through new organisational approaches in farming (Types of Solution), centring on specialisation of management within the farm (e.g., hedge management by contractors, or different rented on-farm enterprises) and building more collaborative structures to increase capacity (e.g., the use of machinery sharing). As the role of social capital in supporting economic performance is better

understood (Svendsen and Svendsen, 2000), encouraging collaborative approaches may provide a way to help farmers tackle challenges and achieve goals together (altering Knowledge and Cognitive barriers). Examples of bottom-up initiatives driving change include the Pont Bren project in Wales (WalesRuralObservatory, 2013) and the spread of community supported agricultural systems (Blättel-Mink et al., 2017). However, bottom-up initiatives often experience tension with top-down institutions, which may struggle to accommodate and support them (Colvin et al., 2014).

The limitations of prescriptive interventions associated with action-orientated agricultural payment schemes are being recognised, prompting moves towards outcomes-driven schemes, giving farmers freedom to determine their strategy for reaching given targets (Burton and Schwarz, 2013).

Empowerment may be achieved through providing enhanced management skills to farmers, enabling them to improve choice-making within a framework in which policymakers work with industry to determine solutions. This may be important, as agency (feeling that one's actions are effective) has been positively correlated with change in other agricultural settings (Inman et al., 2018). However, empowerment which does not address the issue of differing Interests, needs and limitations between stakeholder groups (Kipling et al., 2019), risks change being determined by a particular sector or group, leading to potentially suboptimal outcomes. Increasing diversification of farming systems, ownership and management require policy to work with stakeholders with different relationships to, and reliance on, the land and public support (Lobley and Potter, 2004). To tackle these issues, which concern both the practical implementation of change and the power relations that drive it, platforms for discussion and reflection between stakeholder groups (e.g., not only farmers but also non-farming rural businesses, local people, conservationists, politicians etc.) could empower all stakeholders. Inman et al. (2018) reviewed evidence that in group settings farmers' identities and perceptions of their societal role can alter through 'double loop' learning processes, and that farmers are often keen to engage in group activities, especially when groups are

local. Although challenges relating to mistrust within groups involving different stakeholders were highlighted, other commentators suggest that critical exploration of conflicts between groups (rather avoiding discussion of sensitive problems) is necessary to reach long-term solutions (Johansson and Lindhult, 2008).

Group learning solutions fit to the bottom right of Fig. 4: the co-evolution of more holistic, informed and collaborative Interests between stakeholders. Actions reducing Knowledge and Cognitive limitations could build stakeholders' capacity to articulate and understand each other's views, enhancing the effectiveness of such activities. Change would be based on Interests *evolved* through discussion with other groups, and improved cognitive skills and knowledge shared in well-connected community networks. Technology and data would support stakeholders rather than being used to apply policy to them. Social learning has been applied in many contexts, including climate change adaptation (Ensor and Harvey, 2015) and agricultural sustainability (Nguyen et al., 2014; Toderi et al., 2007) demonstrating the value of developing hybrid farmer-researcher knowledge and emphasizing the need to involve non-farming stakeholder groups in processes of change. In rural development, the philosophy of these approaches has underpinned the European LEADER/Community-led Local Development funding programme for many years (Ray, 2000). However, the role of power relations and Cognitive limitations as challenges for Welsh livestock agriculture (Kipling et al., 2019) draws attention to criticisms of LEADER, including that it has sometimes reinforced inter-community inequality by favouring those with pre-existing capacity to seize opportunities (Cañete et al., 2018) and failed to address intra-community inequality arising from the differing capacities of individuals and groups to engage (i.e. due to differences in confidence and skills and social and cultural barriers), as well as the danger of capture of the process by bodies providing co-funding support (Shucksmith, 2000).

Analysis of Wreford et al. (2017) using the framework created here reveals key aspects of different implementation strategies, enabling the holistic comparison of alternatives and an exploration of their interactions, facilitating coherent strategic action. Top-down and bottom-up models of change are not mutually exclusive, but must be balanced, determining the scope for action by empowered stakeholders within a framework of top-down policy.

4. Conclusions

The framework of solutions to the challenges of implementing GHG mitigation measures presented here can facilitate effective change by drawing attention to key aspects of implementation actions that are often left implicit, namely, what the use of particular intervention tools (e.g., regulation, incentives, social learning) implies in terms of responsibility for change, the level of change and the approach to change, and the types of challenge being targeted. In doing so, the framework enables an exploration of potential complementarities or tensions between different forms of intervention, (e.g., between those relying on mechanisms of top-down control and those relying on bottom-up empowerment) including highlighting the need for (and implications of) actions that encompass and consider the needs, limitations and interests of all stakeholder groups affecting or affected by agricultural production. The framework does not prescribe specific implementation strategies, rather it allows critical assessment of different options, reducing the chance of unintended consequences or conflicting actions. Further work is required to apply the framework to analyse implementation strategies currently applied in specific systems and locations, and to understand the extent to which it may be relevant to other issues and sectors (e.g., action to adapt agricultural systems to climate change).

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626 **Appendix A: Details of stakeholders engaged**

627 Stakeholder groups and number of representatives involved in interviews and workshops (Kipling et al. 2019)

Stakeholder group	Interviews	Workshops
Agricultural industry bodies	5	4
Farm consultants / trainers	1	4
Farmers	1	5
Farming unions	2	4
Policymakers	2	4
Researchers	3	1
Rural interest groups	4	0

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Appendix B: Description of themes arising from the data

The themes were developed using a grounded theory approach (see Methods section in main text) in which comments from participants were coded into themes according to the topics they addressed, with the themes developing as new data were considered (rather than fitting data into pre-existing topic themes). The themes then form the basis for the development of underlying categories which can cross-cut the thematic topics.

Changing agricultural education

This theme related to comments on the need to have a greater emphasis on best practice and sustainability in agricultural education (degrees etc.), including the benefits of increased interactions between farmers and students within education.

Changing the behaviour of non-farming groups in the supply chain

This theme had three aspects, focussing on 1) customer behaviour, 2) societal behaviour and 3) suppliers' behaviour, and considered how farming would change if these three groups recognised what they valued from farming in the prices/rewards offered to farmers and (in the case of suppliers) that other groups did not act in ways likely to make positive change more difficult. Within this theme, farmers retain the responsibility to respond to the changed actions of others in effective ways:

- 1) Perspectives which placed the emphasis for change on the customers for agricultural outputs (public goods as well as produce), i.e. how the market could drive change in farming through the amount customers would pay for these outputs. Aspects related to the amounts paid to farmers by those customers (e.g., increased prices when societal goods like ecosystems services are delivered, including measuring emissions) and the need for these returns to be maintained long-term. This theme also incorporates the conditions of supply (length and terms of contracts) with an emphasis on the need for longer term contracts with stable or fixed prices. It also includes the highlighting of the need for changes in the marketing of different farm outputs to facilitate such changes in customer choices and willingness to pay.
- 2) Relates to statements focussed on the role of government in reflecting societal needs. Specifically, the belief that payments from government should reflect societal goods delivered, making up the difference between public and private benefit
- 3) Focussing on how suppliers behave; this aspect overlaps with changes in societal behaviour in that government intervention was implied in driving/forcing change, i.e. ensuring that information providers within the supply chain (such as vets) make greater efforts to share better quality information with farmers (including by intervention by government and industry bodies to require this)

681 **Co-benefits of change**

682 These often refer to novel systems and approaches and the benefit of recognising the positive
683 impacts they can have beyond GHG emissions mitigation, including:

- 684 1) Multiple production/economic benefits alongside emissions benefits (e.g., increased
685 efficiency
- 686 2) Environmental benefits alongside emissions benefits (e.g., biodiversity)
- 687 3) Social benefits alongside emissions benefits (new jobs, enhanced community
688 interactions) including social pressure acting to change farmer behaviour

689

690 **Cooperation**

691 Comments incorporated into this theme focussed on how cooperative action can enable farmers to
692 address challenges by sharing resources (both physical and in terms of expertise and knowledge).
693 Specific aspects focussed on the benefits of cooperative approaches in the exploration of novel
694 systems and the development of new supply chains (gaining critical mass) and the essential nature
695 of cooperation in the sustainable management of common land. There was also emphasis on
696 cooperation across different stakeholder groups – e.g., collaboration with policymakers to set shared
697 goals, or with industry bodies to collate and share data – as well as on the way that providing
698 ecosystem services, etc. required joined-up action across landscapes, rather than change by
699 individuals acting alone.

700

701 **Data for monitoring and incentives**

702 This theme focussed on the benefits of collecting data about farms in order (with input from experts)
703 to understand what measures and approaches are likely to be most effective, to assess whether
704 change is happening and identify issues and to feed into policy decisions.

705

706 **Easy options**

707 Relates to perspectives emphasising that simple and low effort options for change should be
708 pursued first, including recognising and minimising the costs associated with regulations and
709 paperwork. There was a temporal aspect to these comments, focussing on the need for incremental
710 change with realistic steps, rather than transformational change.

711

712 **Enabling knowledge sharing**

713 Providing arenas and/or technology to enable farmers to gather, share, and develop independent
714 information, knowledge and understanding (links to Use of data by farmers in relating to ways that
715 data can be collected and used by stakeholders themselves)

716

717 **Enabling approaches**

718 Comments associated with the need to enable farmers to drive change themselves and to facilitate
719 this – there were two main aspects:

- 720 1) Provide resources to enable farmers to develop skills and outlooks that empower them
721 to make improved choices
- 722 2) Provide resources and frameworks that enable farmers to implement change flexibly
723 based on their knowledge – moving from telling to partnership

724

725 **Entrepreneurship**

726 This theme was based on comments that focussed on the need for farmers to take ownership of
727 challenges and make the most of opportunities arising from the need to change with an emphasis on
728 investment along the supply chain.

729

730 **Funding**

731 This theme related to comments about the funds that could support change and how they are
732 distributed:

- 733 1) Use of grants that compensate for cost of change
- 734 2) Improve accessibility of grants – simpler systems and application
- 735 3) Top-down grants targeted on policy-determined options, versus bottom up funding for
736 farmer-led change

737

738 **Improving communication**

739 This theme developed from comments focussing on the importance of communication and how it is
740 viewed. It incorporated three aspects:

- 741 1) The need to tailor communication to the specific groups and people being engaged. As
742 well as the importance of considering how will messages might be perceived and
743 interpreted, this also includes how messages might spread beyond the target audience
744 following sharing. Framing and associating messages in terms of the interests of farmers
745 and avoiding top-down instructions were specific aspects mentioned
- 746 2) The need to recognise the value of communication, and that not only the impact of the
747 message, but also the process of communication can produce positive impacts, such as
748 giving farmers more positivity and sense of their own value in the process of change.
- 749 3) Specific approaches – specific ideas about how knowledge exchange and engagement
750 can be improved, including the use of decision support tools, thinking about the timing
751 of message delivery, the circumstances of message delivery (e.g., one-to-one advice) the

752 use of straightforward language, providing space for questioning, and practical
753 demonstration of options in real world conditions relevant and familiar to farmers.

754

755 **Incentives**

756 This theme was formed from comments about the need to incentivise change, including how this
757 can be viewed much more positively (encouraging cooperation and engagement by farmers) than
758 punitive measures that might build opposition. Incentivisation might be achieved by direct
759 payments, but comments incorporated in this theme also overlapped with the theme 'Changing the
760 behaviour of non-farming groups in the supply chain' in terms of ensuring that the market and
761 system more generally acts to reward change once it is made. Three aspects of incentives were
762 could be found in the data:

- 763 1) Tailored incentives – using incentives in a considered way that alters behaviour without
764 causing unintended consequences
- 765 2) Types of incentive – this aspect of the theme relates to 'Co-benefits of change' focussing
766 specifically on the use of improved information to demonstrate to stakeholders how
767 implementation can align their own interests and values (e.g., showing how an option
768 can actually save money or highlighting how measures align with the value farmers place
769 on pure breeds, animal health, pride in performance, money, efficiency, etc.). Incentives
770 may also come in the form of the sharing of information (e.g., between animal suppliers
771 and buyers), incentivising suppliers to improve their product for fear of facing lower
772 prices. Incentives are therefore relevant to suppliers and other stakeholders as well as
773 farmers, and may arise through direct action (payment) or via the market (changing
774 prices). They represent drivers for 'Changing the behaviour of non-farming groups in the
775 supply chain'.
- 776 3) Incentivising measurement of farm processes and outputs that can then enable or focus
777 change (linked to 2) but with more focus on farmers being incentivised by knowledge of
778 how a change is benefitting them.

779

780 **Information research**

781 Research how to best provide advice, develop understanding and facilitate change through
782 identifying needs, learning from examples of good practice elsewhere, collating and making use of
783 understanding based on previous experience and drawing on theories of learning, etc.

784

785 **Joined-up policy**

786 This theme had two aspects:

- 787 1) The importance of consistency in policy across topics and departments (e.g., agriculture,
788 environment, local communities, business, energy, health and safety, food, land use

789 change) ensuring different perspectives, potential opportunities, unintended
790 consequences and interactions with other initiatives are taken into account
791 2) Coordination of policy including its implementation, support mechanisms and KE to
792 improve clarity and reduce uncertainty in the sector

793

794 **Market-driven change**

795 Comments suggesting that the market will drive change, with pressures from along the supply chain
796 forcing farmers to become better at providing the goods and services that are required – links to the
797 relationship between increased production efficiency and reducing GHG emissions.

798

799 **Practical solutions**

800 This theme consists of a series of opinions on specific practical mitigation measures that should be
801 focussed on to mitigate GHG emissions.

802

803 **Quality of information**

804 This theme focuses on the need for decisions to be based on evidence in order to ensure that
805 change is effective in reducing emissions. Specifically, comments highlighted the need to ensure that
806 information provided could be trusted by farmers, i.e. was impartial, taking into account and
807 assessing the different interests of information providers (including researchers). Associated with
808 this, is the need to make sure data are available about all relevant options and conditions – if access
809 to data on some measures or impacts is limited, the picture presented to stakeholders will be biased
810 by the limits of what they receive, even if the information given is in itself objective.

811

812 **Regulate**

813 Comments relating to the way that top-down regulation can be used to prevent damaging practices
814 (including approaches to implementation). These might include specifying minimum standards or
815 prohibiting certain actions in particular contexts.

816

817 **Research**

818 There were two aspects to this theme:

- 819 1) The development of research into new tools and measures, how they work, their
820 efficacy and potential wider impacts (e.g., social, economic, environmental)
- 821 2) Research focussing on how practical and reliable measures are, improving their quality
822 and affordability and giving more insights into how to get the most from them

823

824 **Skills and training**

825 The theme incorporates a range of comments relating to the skills of, and training available to
826 farmers. Three main aspects could be discerned within the theme:

- 827 1) The need for continuous professional development and refreshing of skills for all
828 stakeholders (not only farmers) e.g., including farm advisors and contractors
- 829 2) The need to provide skills relating to the implementation of specific GHG emissions
830 mitigation measures, to ensure effective and safe implementation
- 831 3) The need to enable and increase cross-generational knowledge-sharing (links to
832 'Changing agricultural education')

833

834 **Specialisation**

835 This theme incorporated solutions based on new management approaches, e.g., farm managers
836 overseeing specialised enterprises within a farm. These approaches relate to the ways that large
837 estates are managed and seek to avoid land managers trying to juggle too many systems without
838 being able to develop specialised (best practice) skills in any one. In this case, specialisation is not
839 related to increasing farm size and the choice of one system, but to specialised management of
840 different diverse enterprises on a farm of a given size. Viability might require expert managers
841 working on the same type of system across more than one farm. These solutions relate to changes in
842 the role of farmers and to 'Cooperation' – solutions that make effective use of resources and reduce
843 pressure on individuals.

844

845 **Systems transformation**

846 Views considering agriculture as a whole and determining what needs to happen (e.g.,
847 transformation to new systems rather than adaptation of current systems).

848

849 **Tailored solutions**

850 This theme includes two main aspects relating to understanding how different mitigation measures
851 work, and how they work in different contexts:

- 852 1) Developing more precise solutions, improving knowledge about the various attributes
853 (environmental benefits and implications, economic benefits and demand) of the
854 options themselves (links to research)
- 855 2) Tailoring solutions according to the context for implementation, including type of
856 farmer, location and environment and farming system, and understanding the measures
857 that are likely to work in these different conditions

858

859 **Type of information**

860 This theme is related to different forms of information, and how they might be applied to improve
861 practice:

- 862 1) Comparative information – measuring the effects of change and providing comparisons
863 between farmers to spur change (benchmarking), especially in ways aligned with farmer
864 interests, to drive continued and increased implementation, and to alter practice further
865 if improvements are not observed
- 866 2) Strategic information – about principles, relationships between different actions and
867 parts of the system, and about approaches to managing the system (e.g., having a single,
868 integrated strategy rather than making ad hoc choices in a given area of the farm)
- 869 3) Tailored information – ensuring that information is focussed on specific activities and
870 interactions to ensure best practice

871

872 **Use of data by farmers**

873 The collection and use of data by farmers to improve their own understanding and decision making,
874 including the need to improve access to data to enable farmers to understand how to improve their
875 practice through iterative adjustment over time (link to supply chain interests, as farm customers
876 may not want to highlight good products as farmers would then expect a premium for these). This
877 theme incorporates the sharing of advice between generations and how this improves
878 understanding (see also link to Change in education on this last point).

879

880 **Appendix C**

881 Categorisation of implementation strategies for climate friendly farming in Wreford et al. (2017) using the framework described in the current study. Challenge categories
882 as identified by Kipling et al. (2019): PL = Practical limitations, KL = Knowledge limitations, CL = Cognitive limitations, I = Interests

Wreford et al. (2017) measure	Challenge affected (PL, KL, CL, I) ¹	Level of change (work around, overcome, control) & Approach (accommodate, control, empower)	Notes
Higher & different types of incentive; focus on public vs private cost/benefit & use of incentives/payments	I PL	Overcome (control) Overcome (empower)	Incentives are controlling where they seek to overcome Interests, but can be viewed as empowering if they enable farmers to overcome Practical limitations to do something they wanted to do
Targeted KE to jointly identify change, ways to achieve & policy required to facilitate cheaper / more effective implementation. Included understanding values & reducing the role of entrenched behaviours.	KL, CL I	Work around (accommodate) or alter (empower or control) Work around (accommodate); potential to alter (empower or control)	Engagement as described appears to focus on the benefits of getting groups to agree to changes & therefore ease implementation. However, this interactive process may also alter the Interests of involved groups. Outcomes would depend on the focus, scope & management of the process, & on which stakeholders were involved
Remove policy barriers	PL CL	Alter (empower), potentially overcome (control) Overcome (empower)	Enables farmers to undertake measures that they wanted to but previously could not. However, policy barriers to implementing mitigation might have been in the form of payments or support for practices that the farmer would have liked to continue, so this may also be controlling. Simplifying the system help to overcome Cognitive limitations
Provide information	KL, CL, I	Alter (empower or control)	Specific, limited information and instructions can empower by widening knowledge, however they may also undermine cognitive skills by increasing reliance on externally generated protocols etc. Information might affect Interests with a manipulative or empowering motive
Regulation & prohibition	I, PL, KL, CL	Overcome (control)	Regulation & prohibition assumes Interests of stakeholders are not aligned with measures & acts to overcome, but also forces action despite any practical, knowledge or cognitive limitations
Technology development	PL I	Alter (empower) Overcome (control) or work around (accommodate)	New technology can reduce the cost of/make possible measures farmers wanted but were not previously able to undertake, or align actions farmers wanted to do with mitigation goals. However, if technology is 'sold' to stakeholders (lack of impartial information) it can be used in a controlling way to overcome interests that would otherwise be against implementation

Address barriers of initial investment (cost-share, micro-finance, R&D incentives)	PL, CL CL	Overcome (empower)	Financial resources can make possible measures farmers wanted but were not previously able to undertake, or make measures more attractive. It is less likely than new technology to be used in a controlling way <i>vis a vis</i> Interests. May reduce complexity of making new investment, overcoming Cognitive limitations, enabling farmers to more easily assess their options
Nudge by communicating information about the action of other farmers	I, KL, CL	Alter (empower or control)	Knowledge is increased by information about others which might lead farmers to understand benefits of measures, altering Interests. If the content or form of messages is used to persuade, this may be controlling in focussing cognitive processes on & providing knowledge about externally selected aspects of measures. But information might also give empowering practical, strategic & management insights
Assessment of approaches described in the Scottish Farming for a Better Climate case study within Wreford et al. (2017) review			
Use trusted sources of information	CL, I	Work around (accommodate)	If advice is known to be impartial / trustworthy simplifies farmers' task of decision making, & helps highlight alignment of Interests with proposals
Measures demonstrated on-farm	KL, CL	Work around (accommodate) or alter (empower)	Can aid learning by providing knowledge in a known context, inform strategies & practice & reduce uncertainty about how measures will work
Farmers given arena to discuss mitigation measures with each other & with industry specialists and advisors	KL, CL I	Alter (empower) Alter (empower) or overcome (control)	Discussion can increase knowledge & reduce Cognitive limitations through sharing & working through strategies, approaches & problems. Interests of farmers may be altered by those of other participants, although as the programme is voluntary Interests may already be aligned. Farmers may feel they have to take steps they would rather not due to peer pressure. Depending on the group & process, negative ideas may spread
Based on KE approach shown to improve business performance; focus on efficiency & new opportunities	I	Work around (accommodate)	Focus on demonstrating how measures align with Interests of stakeholders
Simple to implement measures	PL, KL, CL	Work around (accommodate)	Focus on measures not affected by existing barriers
Voluntary approach to foster positive attitude; use of existing discussion groups	I	Work around (accommodate), alter (empower)	Using communication to help farmers see how measures can be in their Interests. The process may also alter Interests as existing groups discuss new topics. Focus on farmers who already want to engage
Regulation considered if voluntary approach fails	I	Overcome (control)	Threat to intervene may overcome farmers' Interests, leading to adoption of un-liked practices
Additional information online on how others have improved efficiency & reduced their carbon footprint	I, KL, CL	Alter (empower or control)	Knowledge increased by information which might lead farmers to understand benefits of measures, altering Interests. If the content or form of messages is used to persuade, this may be controlling in focussing cognitive processes on & providing knowledge about externally selected aspects of measures. But information might also give empowering insights

